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VARIETIES OF TIDES.

BY

ALEXANDER BROWNLIE.

In the article on The Tides of the Pacific Ocean* we called attention to the remarkable fact that tidal action in the North Pacific is absolutely different from that in the South in the very important matter of time-intervals from one high water to the next; the difference is so great that they form two distinct types. In the South the time-intervals are exceedingly regular, whereas in the North they are exceedingly irregular, so in the two sections of the one ocean there are two distinct varieties, wholly unlike each other in their actions.

In the present article we draw attention to a few more cases of variation exhibited in other seas, and show the seeming cause to which the variation is due.

In tidal variation, besides the matter of exceedingly irregular time-intervals, another still more remarkable feature is the failure of flood-tide itself. Commonly, only one of the daily floods will disappear, and that failure continues for a longer or shorter period of time; but at much rarer intervals both disappear completely, and in that event we have the extraordinary spectacle of local sea-level remaining stationary for an entire day.

Now, the science of the tides makes no provision for such failures. Indeed, according to its fundamental doctrines, there ought to be no failure; for, as the moon never falters in its movements, so the tides ought not to fail in theirs. The fact is, however, that failures are not only of frequent occurrence but they exhibit themselves in wide regions of the ocean. For example:

THE GULF OF MEXICO VARIETY.

In the Gulf variety at Galveston, Texas †,

One flood fails to rise 127 times, according to the tables, in 1898.
" " " 165 " " " " 1899.
" " " 217 " " " " 1900.
" " " 139 " " " " 1902.

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* April, 1902, Bulletin Am. Geographical Society, N. Y.

† The United States Tide Tables for Galveston.

During the remainder of each of the given years the forecast for that port is two floods daily,* with the exception of a few days in which both disappear completely—viz., four days in 1900 and two days in 1902. From all this it is clear that the Gulf variety is absolutely distinct from the Atlantic type.

In the Atlantic we find no record of failures. Yet tidal energy enters the Gulf from the Atlantic, with the remarkable result that the thing reproduced bears only a kind of half resemblance to that which produces it. But the fact of a permanent variety existing in the Gulf, absolutely different in its action from that of the Atlantic, points with irresistible force to the conclusion that it is due to a local cause. If this conclusion were erroneous then this variety would not be in existence, for the type of the greater sea would reappear in the smaller ; its existence, therefore, proves clearly that the variation is developed within the Gulf itself, and that it is due wholly to local environment. If this is true in one case, then tidal action may be controlled by the same principle in every case. And that is just what we find; we find it everywhere working in and proceeding from local centres, and not in the form of a globe-travelling wave.

At Galveston there is also a very wide range in the time-intervals from one high water to the next. The widest range, of course, occurs at the periods when one of the floods fails to rise, and then the great range of upwards of twenty-four hours is of very frequent occurrence.†

Now, so wide a range is not in accord with the lunar theory; for, according to it, the movements of flood tide ought to keep step with the movements of the moon.

But the fact of great irregularity, coupled with the notable fact of frequent failures, renders that theory untenable.

As may be seen in the above table, these failures in the Gulf vary greatly from year to year; it is likewise true that they vary from month to month; they also occur in all the phases of the moon; they take place as frequently when the moon is new or full as when it is in 1st and 3d quarters—thus showing clearly that the moon may be left out of the question with entire safety if we seek to solve the problem by TIDAL OBSERVATION alone, and by that method only can practical forecasts be made (*The Tides*, pp. 193, 194, 200).

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* The difference between flood and ebb frequently is only two or three inches; at such times there is practically but one ebb and one flood per day.

† U. S. Tide Tables.

It is also a matter of observation at Galveston that the height to which tides rise is not unfrequently about the same in all the phases of the moon. For instance:

PHASES OF THE MOON.			PREDICTED RISE IN FEET AND TENTHS.	TIME.
New	1st Quarter	Full	each 0.9	February, 1902
New	3d “		“ 0.9	March “
	1st “		1.0	“ “
		“	0.8	“ “
	1st & 3d Quarter	“	“ 1 0	April “
New			1.1	“ “
New		“	“ 1.1	May “
	1st Quarter		1.0	“ “
	“ “		1.0	June “
		“	1.1	“ “
	3d “	“	“ 0 9	August “
New	“ “		“ 0.9	September “
New	“ “		“ 1.0	October “

It will be observed from the table that the height of the rise is altogether contrary to the rule of the theory; for, according to it, if new or full moon can raise water one foot in height, then 1st and 3d quarters ought to raise it only four inches. But in reality, when the waters of the Gulf rise as high at the quarters as at new and full, then the observed fact points to the conclusion that the moon has nothing to do with it. And if the facts of the case disprove the claim of the lunar scientist, what, then, is the cause of the Gulf variety ?

We have already put on record our conclusion that variation is due to local environment. In the case of the Gulf it is clearly due to geographical environment; and in examining the environment it will be seen that the Gulf has two lines of communication with the ocean. These openings are not only comparatively close to one another—for they are situated in the southeasterly corner—but they are very small compared with the vast body of the Gulf.

Roughly speaking, the Strait of Florida and the Yucatan Channel are each about 100 miles wide, but the Gulf itself measures 1,000 miles by 600. From these figures it would appear that the supply of flood tide is very small for so vast a body, and that supply is delivered from the two sources at about the same time.

The supplies are also delivered at right angles to one another; hence the two lines of pressure must speedily come into collision. In fact, a clashing of the two forces is inevitable, and the result is a higher range of floods in that part of the Gulf east of the line of collision.

The highest rise occurs on the western coast of Florida. At Cape Romano and Apalachee Bay the mean is about 2½ feet. On northwest Cuba the range is much less, but at the entrances it amounts to only 1 foot 2 at Key West, Cape San Antonio, and Cape Catoche.

Everywhere else the rise is exceedingly small. On the extreme west of Florida, at Pensacola Bay, sea-level is almost stationary, the mean rise being only one inch. In fact, these small flood tides begin still farther east—at Cape San Blas, and from thence around the Gulf to the Bay of Campeche. The mean range is from one tenth of one foot to six inches at the great majority of the stations. That is to say, two thirds of the whole contour of the Gulf forms a region of exceedingly small tides.

The observed facts in the case of this variety show conclusively that the small rise, in so large a region, is due to the environment; that environment not only grants a short supply, but gives it a direction which leads to a collision of pressures.

The Yucatan Channel supply is directed northerly where the Gulf is 600 miles broad, and the Strait of Florida supply is directed westerly where it is 1,000 miles long.

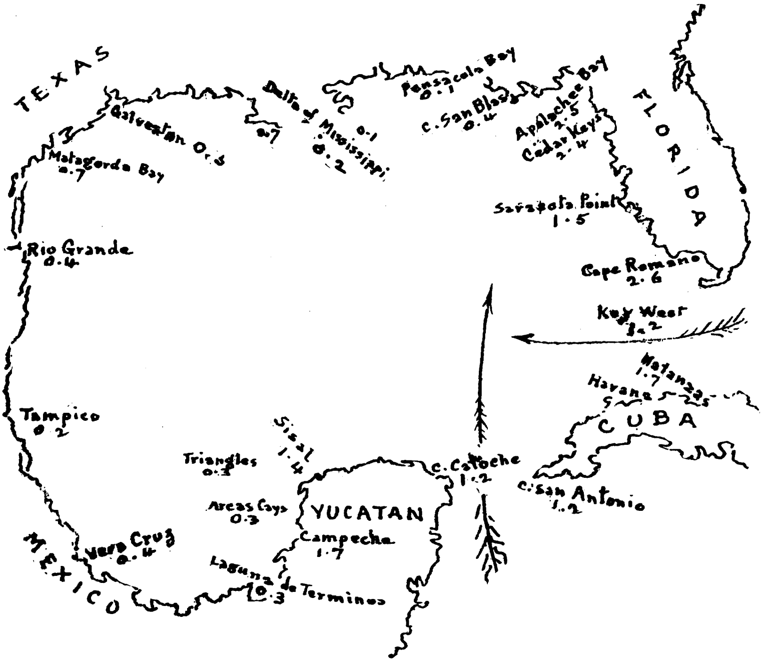
These two lines of pressure, being delivered about the same time and in close proximity to one another, soon clash, with the result that the divergence caused by the greatest pressure shows itself in the largest rise on the coast of Florida, whereas all beyond this region of colliding forces becomes a region of exceedingly small tides—so small, indeed, as to escape the notice of an ordinary observer.

There remains for us to notice only one more well-known physical feature of the Gulf—that is, its currents. A perennial oceanic current enters through the Yucatan Channel and leaves the Gulf by the Strait of Florida; but even if that factor were absent, this variety would still remain absolutely distinct from the type of the Atlantic because of its geographical environment.

This variety does not extend to Key West. That port follows the type of the Atlantic with two floods daily, but the time-intervals are far from being as regular as they are in the Atlantic. For instance, in the tables for January, 1902, we find the following extreme range in the times between one high water and the next:

	HOUR.	MIN.		HOUR.	MIN.
Forecasts for Key West...	11	07	to	13	47
" " Charleston...	12	13	"	12	52
" " Sandy Hook..	12	09	"	12	47

By the table it will be seen that while the extreme variation at Charleston and Sandy Hook is only 39 minutes, it is 2 hours 40 minutes at Key West.



SKETCH MAP OF THE GULF of MEXICO SHOWING THE MEETING PLACE OF TIDAL PRESSURES FROM THE TWO SOURCES OF SUPPLY AND THEREBY EXPLAINING THE CAUSE OF THE VARIATION IN TIDES. THE FIGURES GIVE HEIGHT OF RISE IN FEET AND TENTHS. THE ARROWS SHOW THE TREND OF THE PRESSURES.

SEA OF JAVA VARIETY.

At Batavia, Java, the most remarkable feature of this variety is the frequency of the failure of flood tide. In fact, the failure of one daily flood forms the rule and days with two floods the exception. For instance:

There are 38 days with two floods, according to the tables in 1898*
" 41 " " " 1899
" 32 " " " 1900
" 15 " " " 1902

In the above table we take no notice of enumerated floods where the difference between flood and ebb amounts to only two tenths of an inch, for then practically there is no visible change of sea-level.

It is on record that for weeks at a time currents have flowed through the Strait of Sunda. Then for a similar length of time they have flowed back again without showing any perceptible rise or fall of sea-level. †

Moreover, in the forecasts for Batavia in the four years named there are fifteen days in which both floods disappear completely. And at this port it not infrequently happens that floods rise as high, or even higher, at the quarters than at new moon or full. For instance:

3d	Quarter,	2	feet	4	New,	2.3	Full,	2.6	Feb.,	1898
"	"	2	"	5	"	1.9	"	2.1	Mar.,	"
"	"	2	"	7	"	2.6	"	2.3	Apr.,	"
1st	"	2	"	6	"	1.9	"	2.1	Sept.,	"
"	"	2	"	5	"	2.3	"	2.7	Oct.,	"
3d	"	2	"	8			"	2.7	Feb.,	1899
"	"	2	"	9	"	2.3	"	2.4	Mar.,	"
"	"	3	"	0	"	2.9			Apr.,	"
1st	"	3	"	0	"	2.3	"	2.2	Sept.,	"
"	"	3	"	0	"	2.6			Oct.,	"

The heights of rise at the quarters, given in the above table, make a remarkable commentary upon the seventeenth century science. And, in view of the failures of that science, it is to-day worthless for practical forecasting, for these cannot be made by a knowledge of the science only; but they can be made more or less correctly by observation at any place, and that, too, by men who have no knowledge of the science whatever. (See our reference to *The Tides*, page 2 of this article.)

The sea of Java has several openings communicating with the ocean; but the largest of these lead into other enclosed seas, and in this larger local environment must be sought the full explanation of all the vagaries of the variety.

THE MANILA VARIETY.

At Manila (Corregidor Island), according to the tables for 1902, only about one hundred days in that year have two floods. During the remainder of the year, practically speaking, there is but one daily, excepting a few days when there is none at all.

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* U. S. Tide Tables for Batavia.

† London Shipping World.

BERING SEA VARIETY.

What we have to say regarding this variety refers to observations taken at St. Michael, Norton Sound. They were taken during the open season for navigation, June to October, and in these five months, according to our tables,

37 days have two floods in 1900
39 " " " " " 1902

During the remainder of the season there is but one daily, excepting a few days in which there is none.

One peculiar feature in this variety is the great number of failures in June and July. In these months two floods occur only upon one or two days each.

The environment of this variety is peculiar, in that it lies between two more varieties, whose communications are nearly closed on one side—viz., the North Pacific Ocean and that region of the Arctic immediately adjoining Bering Strait.

At St. Michael gales are of frequent occurrence during autumn, and when a strong one blows from the north for several days, sea-level may fall as much as five feet below mean low water.*

Both the Manila and Bering Sea varieties are only recent additions in the U. S. Tide Tables, and we have no information as to their extent beyond the small spots where they are now observed.

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* U. S. Tide Tables for St. Michael, 1902, p. 165.

(*To be continued.*)